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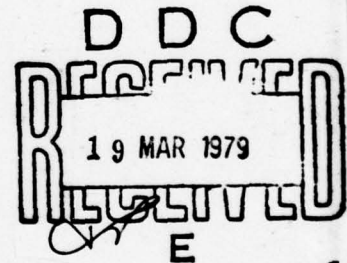
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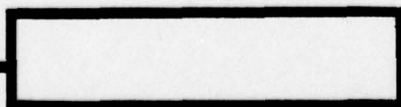
PROTECTIVE ZONE OF THE LIGHTING ROD

by

M. Krstic



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PROTECTIVE ZONE OF THE LIGHTNING ROD*

Mihajlo Krstic**

INTRODUCTION

The use of Franklin's lightning rod has shown very visible, practical results for protecting objects from atmospheric electricity. An indisputable theory has been developed on the basis of practical experience which proved that there is a conical protective zone, a space in the form of a true or truncated cone which surrounds the lightning rod which represents an effective protection for all objects located within the boundaries of this cone. Lightning cannot strike the objects in the cone, but strikes only the tip of the lightning rod.

This means that the lightning rod forms a space around itself, which protects objects from a direct strike. This protected space is referred to as a protective zone and has the form of a cone. For an object to be protected from a direct strike by lightning, it must be located completely inside the boundaries of this cone (including all its parts). The effective size of the protective zone depends also upon the number and mutual relationship of lightning rods, the altitude of the storm clouds and the position of the storm clouds with respect to the lightning rod.

A lightning rod may be installed separately next to the object to be protected, or may be placed directly on the object. Depending

*Report from III Yugoslav Council on Geoelectricity and Lightning Rods. Arandjelovac, May, 1975.

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upon the need, the lightning rods may or may not be insulated from the protected object. Insulated lightning rods may be made of impregnated wood, varying in height up to 30 meters with a tip of the type B 100 JUS N, B4. 902 and a few supports of the type A 80 JUS N. B4 925 which carry the strip Fe/Zn 25x4 (20x3) mm. The end of the strip is grounded.

A second type of lightning rod in current use is a steel tube composed of a number of different diameter tubes and ranging in length up to 25 meters. The **steel** post has an appropriate tip at the top. The post, which represents a homogeneous vertical conductor, is connected at the bottom to the ground by a strip.

A third type of lightning rod is a perforated steel post up to 20 meters high, which has an appropriate tip at the top. At the bottom it is welded to an angle plate and connected to the ground by a strip.

A fourth type of lightning rod is represented by a concrete post up to 20 meters high. At the top, an appropriate tip is welded to reinforcing metal rods which lead down vertically along the post. At about 0.5 meters above the ground the rods are connected to a steel plate which is grounded by a zinc-plated steel strip Fe/Zn 25x4 mm.

According to all existing regulations, every lightning rod must have a tip, a vertical conductor and a group connection. The current of the lightning must be led directly to the ground where it is dissipated. Lightning rods are grounded by a zinc-plated steel tube (of prescribed length) type 3000/75 JUS N. B4. 942 and a zinc-plated steel strip Fe/Zn 25x4 mm.

Lightning arresters in the form of a wire - sometimes referred to as lightning arrester rope - are used for the protection of high

voltage cables.

INSTALLATION OF LIGHTNING RODS

Every lightning rod, regardless of the type or height, must be placed 3 to 5 meters from the object of concern. This is in order to ensure that a lightning strike will be attracted to the rod. Rods, tips, and supports and ground connections must all conform to regulations and standards. In exceptional cases, mechanical and statistical calculations must be made for the rods, as well as calculations for the magnitude of ground resistance to dissipation of a lightning strike.

A lightning rod is, in effect, represented by the tip placed on top of a post at a height exceeding that of the object to be protected. The number of lightning rods, their distribution and height, depend upon the size of the object and/or the area that is to be protected.

ZONE PROTECTED BY A LIGHTNING ROD

On the basis of many years of experience, the best recommended conical zone ranges in angles between 30° and 60° . It is claimed that lightning can never strike within this conical space (inside its boundaries). This means that an object is completely within the protected zone only when the lightning rod is substantially above the object.

It is readily seen in Figure 1 that a protected zone is defined by a single lightning rod. It is thus apparent that a protected zone with an angle of 30° represents the best protection, and that the protection is reduced as the angle is increased.

The protected zone of a lightning rod of height h is represented in Figure 2 by a cone whose outer side appears as a broken line. The

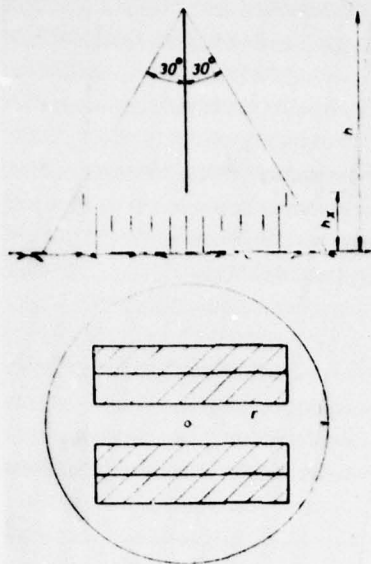


Figure 1.

base of the cone has a radius $r = 1.5h$.

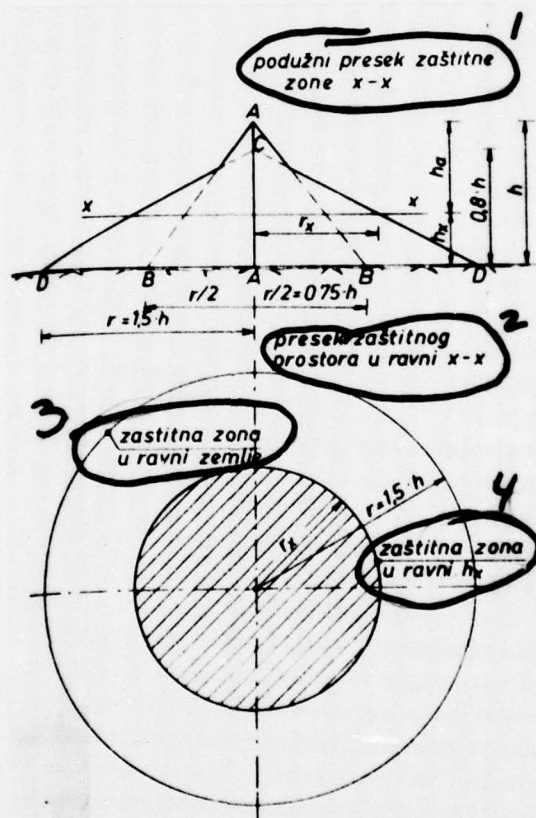


Figure 2. Key: 1- longitudinal cross-section of the protected zone $x-x$.
 2. cross-section of the protected area in the $x-x$ plane.
 3. protected zone at ground level plane
 4. protected zone plane at h_x .

The horizontal cross-section $x-x$ of the protected zone at the h_x level of the protected object represents a protected circle of

radius r_x . The active height of the lightning rod is h_a .

The broken line formed in this way represents the limit of the protected zone. Rotating the broken line about the axis of the lightning rod A-A forms a cone representing the space within which the objects are protected with sufficient certainty from lightning strikes.

The following two expressions are available for calculations of the radius r_x and height h_x of the protective zone.

1. If $h \leq 60$ meters, and

$$h_x < 2/3 h$$

$$r_x = 1.5 (h - 1.25 h_x)$$

2. If $h > 60$ meters, and

$$h_x > 2/3 h$$

$$r_x = 0.75 (h - h_x)$$

Figure 3 shows a general example of the protected zone of a lightning rod as applied in the Soviet Union according to their regulations. The height of the object is $h_x = 2/3 h$, where h is the height of the lightning rod. The protected space is calculated starting at $0.8 h$ and the radius of the protected zone is $1.5 h$ at the ground level.

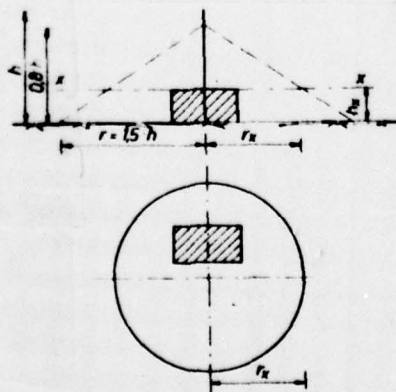


Figure 3.

The drawing viewed at the ground level, i.e., at the base, represents a protected zone at the height h_x with radius r_x . This type of protection is applied for low objects.

Figure 4 shows a method of protecting high objects by a lightning rod placed on the roof of a building. This method is used in the Soviet Union. If the height to be protected exceeds 60 meters, then (the height of the protected zone) $h_x > 2/3 h$. Here, h represents the total height of the lightning rod (from the ground to the tip of the lightning rod). The protected zone is considered to have $0.8 h$ and the radius of protection on the ground level is $1.5 h$, and consequently $r/2 = 0.75 h$. This method of protection is applied to high objects. The height of the protected zone is at h_x and the radius of protection is r_x .

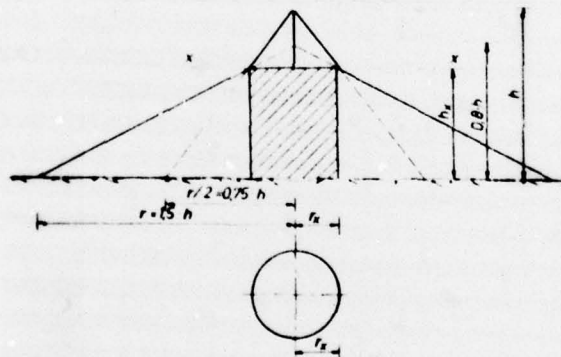


Figure 4

Figure 5 illustrates a method of protecting objects by tubular lightning rods which are used in Czechoslovakia. According to their regulations, the height of the lightning rod must be $h = r$. The protected object must be more than 2 meters within the conical protected zone. This type of protection is applied for structures that contain explosives.

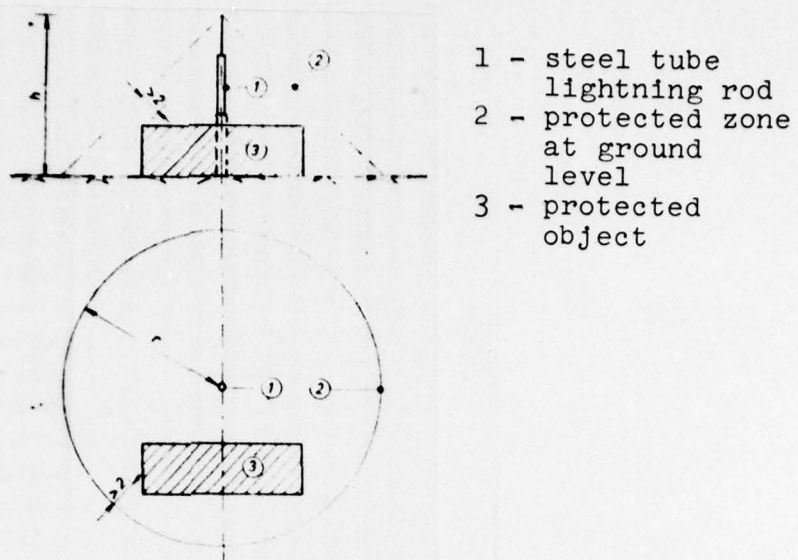


Figure 5

Figure 6 illustrates a method where $r = h$ is assumed for the protected zone with the requirement that the objects be placed deeper within the protected zone. This method of protection is standard in America.

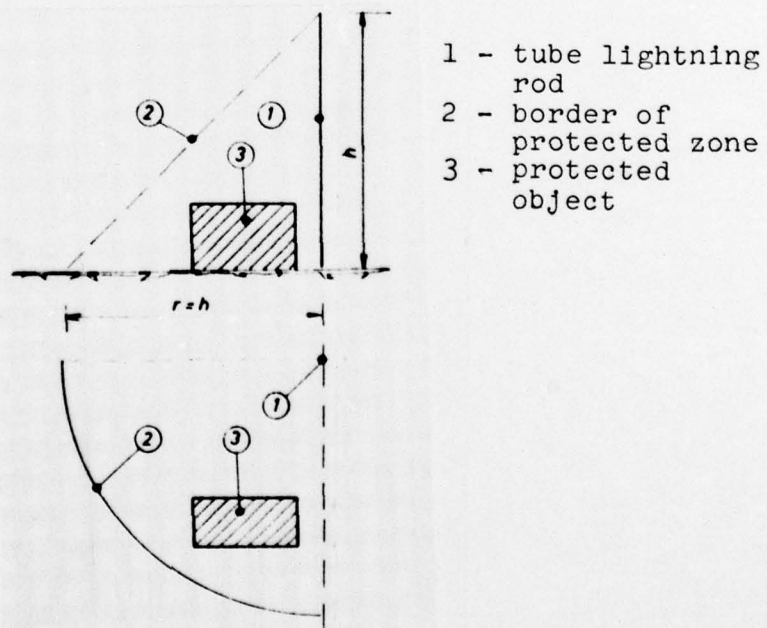


Figure 6

Figure 7 illustrates the protection of a few objects by one, two, or more lightning rods at some distance from the objects. The height of the lightning rod is $h = 15$ meters so that the radius of the protected zone at the ground level will be $r = 1.5 h = 1.5 \times 15 = 22$ meters. The distance between objects and the lightning rod is $h/4 = 3.75$ meters which conforms with the distance requirements. The edge of the objects must be at a distance $d \geq 2$ meters from the limits of the protected zone.

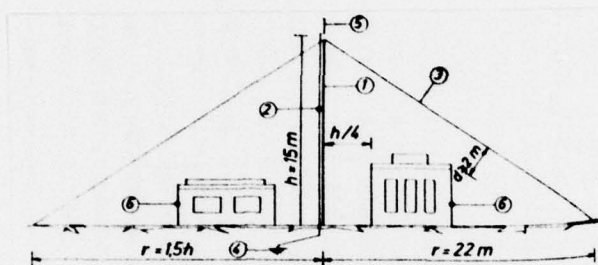


Figure 7. Key: 1- lightning rod 2- vertical conductor 3- protected zone boundaries 4- ground 5- tip 6- protected object.

Figure 8 illustrates a different way of protecting an object. As may be readily observed, the object to be protected is only partially within the protected zone at its corresponding height, and is placed too far from the lightning rod. The radius of the protected zone must be $r = 2h$. This is improper.

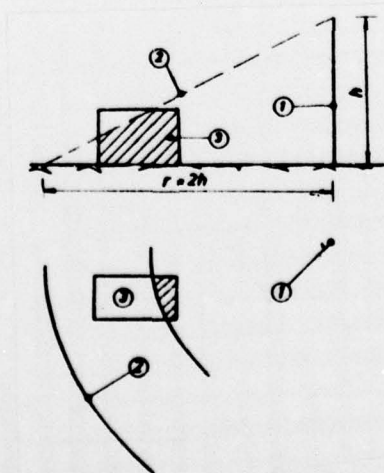


Figure 8

Figure 9 illustrates the protection of an object by lightning rods and a stretched zinc-plated steel wire of 6 mm diameter. Two lightning rods are placed at the far left and right side of the objects, and a wire is installed 1.5 meters above the top of the object. The building is of a short type (15 m). There are no lightning rods installed on the object itself.

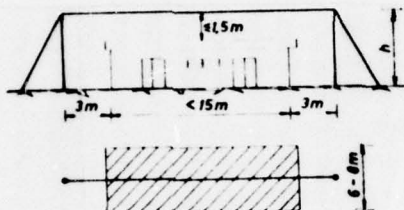


Figure 9

If the object exceeds the length of 15 meters (see Figure 10), four lightning rods are used in the manner shown in the Figure.

If there are many objects lined up in a row, or a group of several objects (see Figure 11), the lightning rods are placed between the objects so that their protected zone covers all objects.

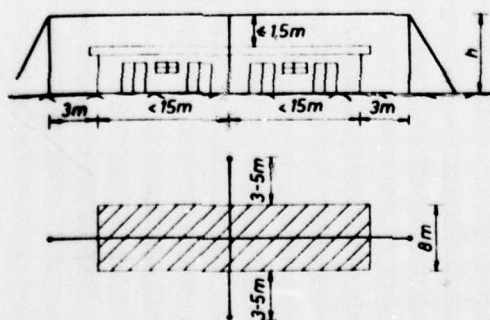


Figure 10

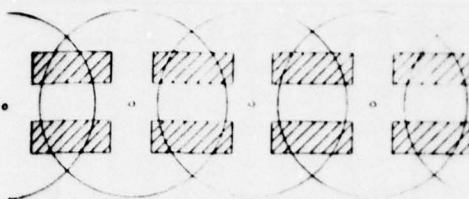


Figure 11

Network lightning arresters (see Figure 12) consist of crossed wires mounted on rods above the protected objects and at a proper distance from the objects. The net above the protected objects may be installed either in the form of a rectangle or a square, as long as the wire is placed horizontally 1 to 1.5 meters above the top of the object. The open sections of the network should be 5x5 meters in size. The outer positions must be mechanically supported and be equipped with a tip at a height of 300 mm.

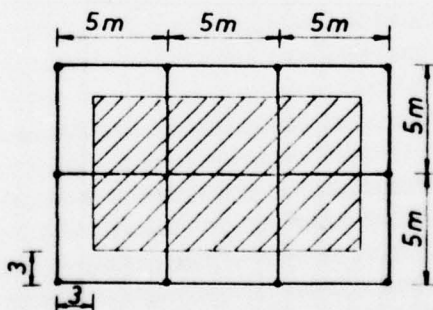


Figure 12

ZONE PROTECTED BY TWO LIGHTNING RODS

A zone protected by two lightning rods is illustrated in Figure 13. The lightning rods do not exceed 60 m in height and are placed at distance a from each other. The boundary between two lightning rods of the same height is represented by an arc of a circle passing through the tips of the lightning rods centered on the vertical line 0-0 at

at elevation $H = 4h$. The left and right side of the protected zone are determined in the same manner as for individual lightning rods.

The contour of the zone in its vertical cross-section plane midway between the two lightning rods is determined according to the rules for the formation of a protected zone by a single lightning rod of height h_0 . This corresponds to the minimum height of the zone between the two lightning rods. In this case the magnitudes of r_0 and r_{0x} are numerically equal to a half-width of the protected zone at the middle between the lightning rods. The value at the ground level is r_0 and at the height h_x is r_{0x} .

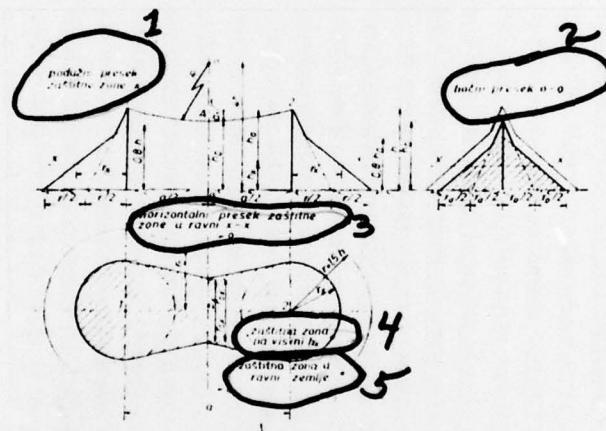


Figure 13: Key: 1- longitudinal cross-section of the protected zone x-x; 2- side cross-section o-o; 3- horizontal cross-section of the protected zone in the x-x plane 4- protected zone at height h_x , 5- protected zone at ground level.

It follows from the diagram that for all lightning rods having height $h \leq 30$ meters, the smallest width of the protective zone is b_x for any height h_x . However, one must keep in mind that the value for b_x derives from the relation $a/h = 0 - 7$. If the lightning rod exceeds the height of $h \geq 30$ meters, the values obtained for the

abscissa and ordinate must be multiplied by the coefficient $P = \frac{5,5}{\sqrt{h}}$ where h is given in meters.

The height of the protected object h_o is given by expressions:

$$\text{for } h \leq 30 \text{ meters,} \quad h_o = h - \frac{a}{7} \text{ met.}$$

$$\text{for } h > 30 \text{ meters,} \quad h_o = h - \frac{a}{7} \cdot \frac{5,5}{\sqrt{h}} \text{ met.}$$

where a represents the distance between the lightning rods, h represents the height of the lightning rods and h_o represents the lowest height of the protected zone between the two lightning rods.

ZONE PROTECTED BY TWO LIGHTNING RODS OF DIFFERENT HEIGHTS

The protected zone of two lightning rods of different heights is illustrated in Figure 14. The height of one rod is h_1 and the height of the other is h_2 ,

The width r_{ox} of the protected space (below the height h_o) and the height of the protected space are given by the expressions:

$$\text{for } h \leq 30 \text{ meters,} \quad h_x \leq 2/3 h$$

$$r_{ox} = 1.5 (h_o - 1.25 h_x)$$

For lightning rods that are higher than 30 meters, we have the expressions:

$$h_x > 2/3 h$$

$$r_{ox} = 0.75 (h_o - h_x)$$

In addition, when the height of the smaller lightning rod is $h \leq 30$ meters, we have the expression:

$$h_b = h_i - \frac{a_i}{7} \text{ met.}$$

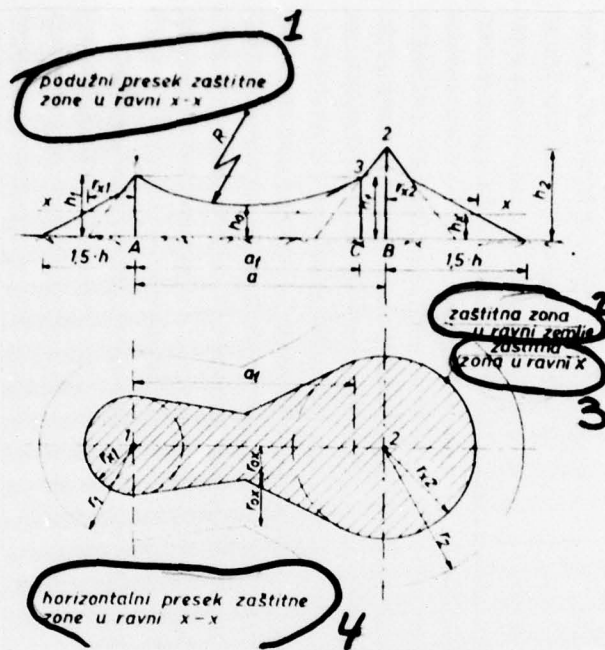


Figure 14. Key: 1- the longitudinal cross-section of the protected zone in the x-x plane 2- the protected zone at ground level 3- the protected zone in plane x 4- the horizontal cross-section of the protected zone in the plane x-x.

ZONE PROTECTED BY THREE OR FOUR LIGHTNING RODS

The zone protected by three, four, or more lightning rods (see Figure 15) is determined by combining single lightning rods with two others, which are regarded as a double lightning rod.

The basic requirement for the protection of objects of height h_x or a group of objects where the tallest has height h_x is that r_{ox} is greater than 0 (for all combined lightning rods). In addition, when four or more lightning rods are used, the following requirements must be fulfilled:

a. For low objects, it is necessary that $h_o \geq h_x$ for lightning rod pairs. The pairs are formed by combining lightning rods across the diagonals of polygons formed by the lightning rods.

b. For other objects, the requirement is that $D \geq 5h$ where D represents the diagonal length of polygons formed by lightning rods.

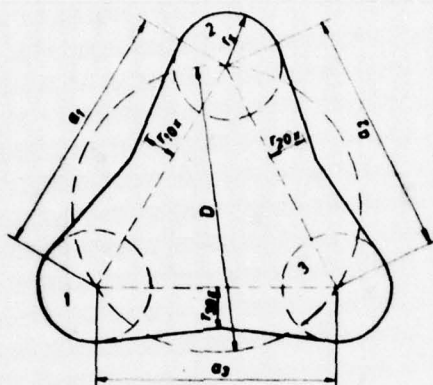


Figure 15

$$\text{if } h \leq 30 \text{ meters,} \quad D \leq 8(h - h_x)$$

$$\text{if } h > 30 \text{ meters,} \quad D \geq 8 \cdot \frac{5.5}{\sqrt{h}} (h - h_x)$$

here h represents the height of the lightning rod, and h_x represents the height of the object to be protected.

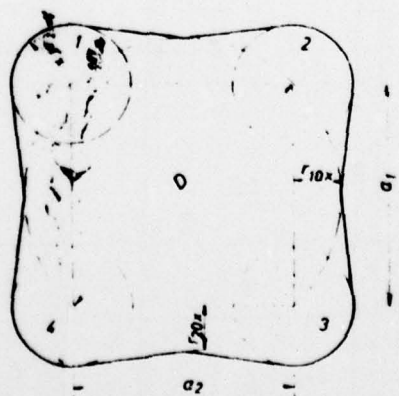


Figure 16

Figure 17 illustrates a protected area (at height h_x) produced by four arbitrarily placed lightning rods. All lightning rods have the same height and r_x is the radius of a zone protected by one lightning rod.

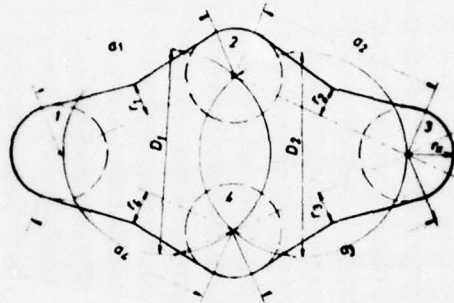


Figure 17

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